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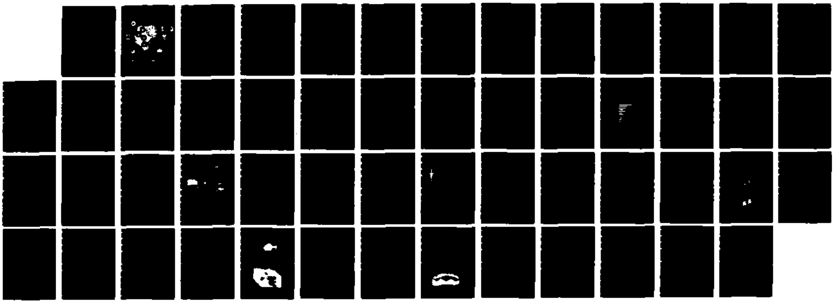
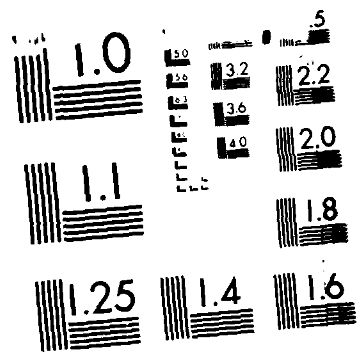


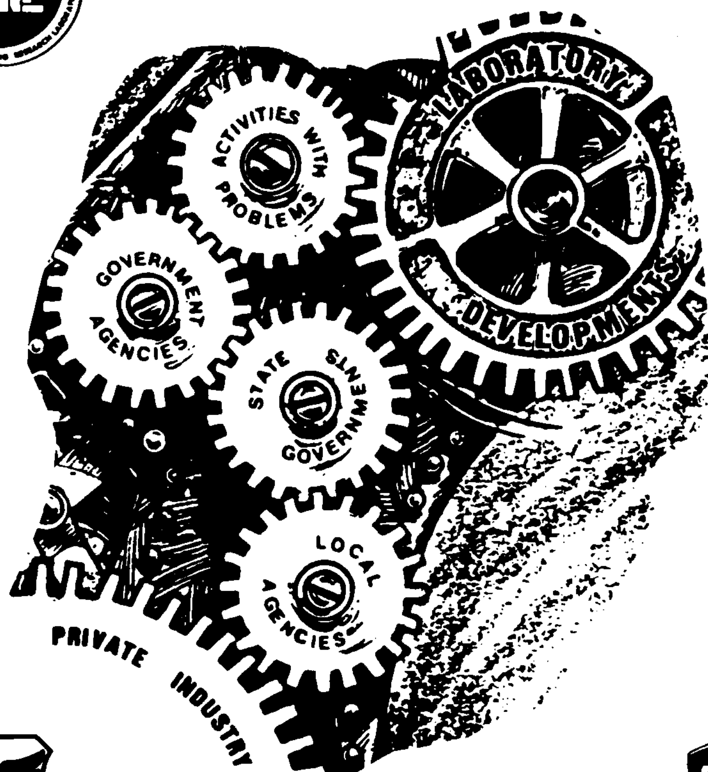


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS

TECHNOLOGY TRANSFER OPPORTUNITIES

FOR THE

CONSTRUCTION ENGINEERING COMMUNITY



MATERIALS & DIAGNOSTICS

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SOCIETY OF AMERICAN MILITARY ENGINEERS
DOD CONSTRUCTION R&D LABORATORIES
FEBRUARY 25-27, 1986

Technology Transfer Opportunities
for the
Construction Engineering Community

MATERIALS & DIAGNOSTICS

Co-sponsored by
Society of American Military Engineers
DOD Construction R&D Laboratories
February 25-27, 1986

Special Report 86-1

U.S. ARMY COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

INTRODUCTION

The Society of American Military Engineers hosted a series of briefings by the Department of Defense Research & Development Laboratories on February 25-27, 1986, on the subject of transfer of technology to private industry. The briefings were aimed at A&E firms, construction contractors, equipment and material manufacturers, government agencies, universities and research groups. The objectives were:

1. To provide information about marketable technologies available from the DOD construction and engineering R&D centers and laboratory community.

2. To identify selected current and future technology needs in DOD construction and engineering research and development.

3. To promote dialogue between the DOD construction laboratory community and the construction industry.

The briefings were divided into five sessions: Construction, Energy, Environment, Materials & Diagnostics, and Mobilization Readiness & Logistics. This document represents summary papers from the Materials & Diagnostics session. For additional copies of this or other sessions, contact:

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Naval Civil Engineering Laboratory
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Port Hueneme, CA 93043

or telephone 805-982-4292.

CONTENTS

Coatings Developments and Needs

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ABSTRACT

The Army Corps of Engineers research in the field of coatings originated with the need to develop more durable coatings for the protection of the locks and dams on the rivers. The exposure is one of constant immersion in addition to an extreme amount of abrasion due to floating ice, logs, and other debris. Research has included the evaluation of virtually every generic type of coating; an intensive amount of formulation work was done in addition to the evaluation of many propritary products. This research program has lead to the development of a series of solution vinyl coatings which have application and performance properties superior to any other coatings evaluated. The coatings have provided complete corrosion protection without maintenance to steel structures in the absence of abrasion for over 30 years and have provided a greater amount of protection in areas of abrasion than other coatings when applied on side-by-side field tests. The coatings are applied to sandblasted steel at ambiant temperatures as low as 20 degrees F and surface temperatures as high as 125 degrees F. Although film build per coat is quite low the coatings dry sufficiently fast that the entire paint system can be applied in a matter of hours.

In addition to the Corps use of these coatings on locks and dams it has been learned that private industry is using them on such items as interiors and exteriors of water storage tanks, in swimming pools and on farm equipment and industrial earth moving equipment which might be subject to large amounts of abrasion. Formulations for the coatings are published in the Corps of Engineers guide specification CW-09940 "Painting: Hydraulic Structures and Appurtenant Works" as well as in the annual Rock Island District Paint Procument Contract.

In another ~~program a~~ study revealed that the majority of paint used by the facility engineers (FE) is not tested for specification compliance. Reasons for not testing often included the costs and time required to conduct the laboratory work. In order to address this problem USA-CERL undertook a program to develop a paint testing kit which would enable the FE inspector to perform some basic tests on a liquid sample of paint. Obviously it is impossible for an inspector to have all the necessary expertise and expensive equipment necessary to conduct specification tests for all paints. Therefore, in the development of the kit it was decided to use simple equipment and nontechnical procedures in order to determine basic paint qualities.

The resulting brief case size kit is being procured by the government for less than $300 each. It is capable of performing 14 different tests on any common latex or oil base paint. The kit tests basic qualities such as:

Does the paint sag? Does it dry? Does it hide? Does it have an acceptable appearance? Is the gloss at the proper level? Can it be cleaned? Tests results are compared to standards in a manual which accompanies the kit. It is intended that the kit be used as a screening device; paints which do not appear to be equal to a standard should be sent to a testing laboratory for more sophisticated testing.

Laboratory evaluation of the kit has proven the reliability of the tests as performed on a variety of interior and exterior latex and oil based paints. However, testing of high performance coatings such as epoxies, urethanes, etc. is not within the design capabilities of the kit. A small scale field evaluation of the kit produced positive response and a field evaluation involving 100 kits is currently underway.

A current program involves the desire to paint steel structures which are immersed in water and cannot be dewatered. Projects include evaluating commercially available surface preparation equipment, application equipment and coatings as well as attempting to formulate new types of coatings for underwater application.

FACILITY DIAGNOSTICS

by

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The Navy now owns $90 billion worth of shore facilities. Most of these facilities were built between 1940 and 1945 and are showing signs of wear and deterioration. In order to keep these facilities in condition to support fleet requiredments, there is an ever increasing need for timely maintenance, repair, or rehabilitation. The Navy currently spends about $1 billion per year on maintenance and repair. This is only about 1% of plant value and is far below industry standards for many specialized or one-of-a-kind facilities.

As the MILCON programs grow to support increasing defense technology, the need for increased maintenance and repair will continue to be a major problem. Recognizing this ever growing problem, the Naval Civil Engineering Laboratory (NCEL) has initiated a project to identify, develop, and apply technology to rapidly, accurately, and nondestructively assess the quality of new construction and the condition of the Navy's existing shore facilities to support fleet operations and other mission requirements.

This project at NCEL is being structured to:

- Identify, apply, and test existing technology for evaluating the performance and durability of construction materials and building components as related to ensuring quality of construction.

- Apply nondestructive technology (i.e., hardware, software) to assess the condition of a facility and develop, maintain, repair, or replace decision criteria.

- Apply analytical/economic models to predict life cycle costs or remaining service life to identify areas that are critical to maintaining operational readiness.

- Establish a Navy wide program for the continuing diagnosis and condition assessment of facilities in service.

Currently identified areas requiring an infusion of diagnostic technology include:

- Assessing the condition of steam and condensate utility distribution systems, sewer systems, and electrical systems.

- Diagnostic procedures and repair protocols for concrete spalling, cracking, and deterioration due to chemical attack, rust staining, and sea wave action.

- Lube oil analysis techniques, suitable for field use, to detect early degradation of dynamic equipment.

- Remote monitoring and analysis technology to provide labor savings and increase diagnostic capability.

- Reducing waterfront pump and motor failures due to corrosion and water intrusion by application of new materials or designs.

The above list is a small sample of the Navy's needs in the area of diagnostics, condition assessment, and facility maintenance. The project at NCEL is in a developmental stage. The staff is collecting detailed information on the Navy's diagnostic needs, identifying centers for expertise, identifying appropriate technology, and assessing the application of the technology to the Navy's need.

ACKNOWLEDGEMENT

This development effort is being sponsored by the Naval Facilities Engineering Command, Alexandria, Va.

RECYCLED CONCRETE AS AGGREGATE

By

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Introduction

While in its broadest sense the term recycled concrete would refer to any reuse, this paper will be specifically devoted to the reuse of old concrete as coarse or fine aggregate or both in portland-cement concrete.

There is now a need to recycle waste concrete for several reasons. These include:

a. Conservation. Any reuse of old concrete as aggregate conserves our existing supplies of natural aggregates.

b. Reuse of waste concrete helps to reduce our solid waste disposal problem.

c. The shorter haul distances that are likely with recycled concrete save energy in the form of fuel.

One purpose of this narrative is to acquaint the reader with the concept that recycled concrete can be a satisfactory aggregate. Another purpose is to encourage people to think of it as a potential aggregate source when they need aggregate. In that context many of the usual considerations for conventional aggregates will also apply to recycled concrete. Specifications now recognize recycled concrete as aggregate. ASTM C 33-82, "Standard Specifications for Concrete Aggregates," in 1982 added crushed hydraulic-cement concrete to its list of aggregates.

Research

Ploger[1] started the research in this country in 1947. This was followed by work done at the Waterways Experiment Station (WES)[2-4] in 1972 and 1976. Shortly thereafter some work was done in Canada[5] and at the Massachusetts Institute of Technology (MIT).[6] All of this work concentrated on evaluating the properties of aggregates made from recycled concrete and of concretes made with these aggregates. Work at WES included use of three old concretes as coarse or as coarse and fine aggregate in several concrete mixtures. One of the old concretes had been made with local chert gravel and natural sand; one with a granitic coarse and fine aggregate; one with a carbonate crushed coarse aggregate and a natural sand. Thus, two of the old concretes contained siliceous aggregates while the third contained both carbonated and siliceous aggregates. WES findings were as follows:

Aggregates

a. Aggregates made from old concrete have lower specific gravities and higher absorptions than is typical of conventional aggregates.

b. Particle shapes tend to be three dimensional and are satisfactory.

Concretes

a. Workability is satisfactory.

b. Compressive strength of concrete containing recycled concrete aggregate is lower by as much as 1100 psi (8 MPa) than that of concrete of the same water-cement ratio and similar conventional aggregates. This is shown by Figure 1. However, equal strengths can be obtained by appropriate mixture modification (use of a water reducer, more cement, etc.).

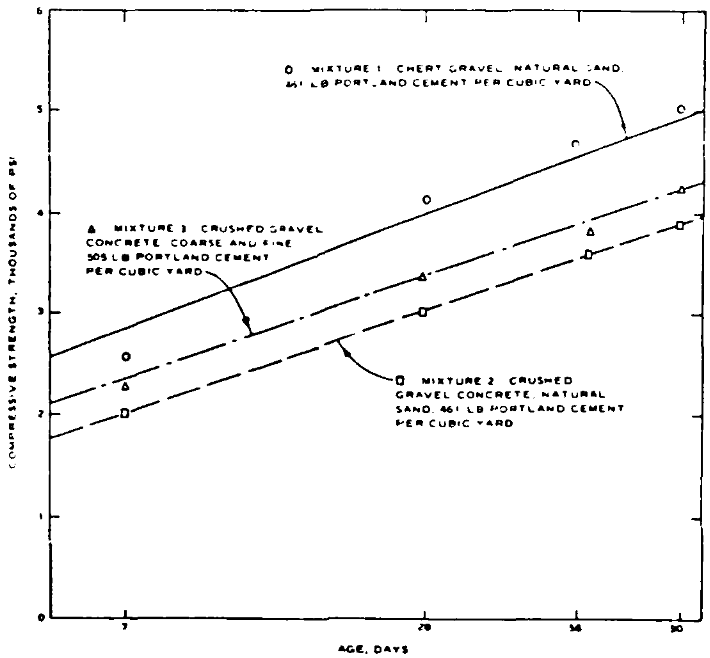

Figure 1

c. The use of old concrete of low strength is not a limiting factor on the strength of new concrete made with this recycled concrete as aggregate.

d. Use of recycled concrete as sand requires the use of about one extra bag of cement per cu yd of concrete.

e. Frost resistance of the concrete containing recycled concrete which contained chert gravel as original aggregate was improved by a factor of five or more. This was ascribed to the sealing effect of the original portland-cement paste on the porous aggregate particles. The frost resistance of concrete mixtures containing other recycled concretes as aggregates was similar to companion control mixtures.

f. The sulfate content of building rubble used as aggregate must be controlled since it can lead to chemical reaction and deleterious expansion.

Other research[1,5,6] generally agreed with the above findings. The overall conclusion to be drawn from this research was that such recycling was both desirable and feasible.

The major needs for recycling of concrete as aggregate are for specially designed processing equipment, for experience in removing reinforcing steel, and for data on the economics of recycling.

Acknowledgment

Funds for the laboratory work and reports were provided by the Assistant Secretary of the Army "In-House Laboratory Independent Research Program" and by the Concrete Technology Information Analysis Center.

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ACCELERATED PAINT TESTING

by

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BACKGROUND

The Navy spends about $80 million annually on painting operations to protect shore facilities with a real property value of $90 billion. About two-thirds of this painting is done by contract and one-third in house, with contract painting expected to increase further. The Federal Acquisition Regulation (FAR) is the primary regulation used by all Federal Executive agencies in their acquisition of supplies and services with appropriated funds. The two major goals of FAR are to promote full and free competion and to meet only minimum requirements. The latter is usually interpreted as to accomplish minimum life cycle costs rather than to satisfy minimum immediate needs.

In the low-bid acquisition system dictated by FAR, some bidders read the contract specification carefully for possible interpretations they can use to their advantage. They may bid with the intention of providing less than desired or making a profit on a change order or claim based on vague, incomplete, or contradictory wording. Thus, sizeable claims for additional costs on painting contracts are not unusual.

Federal and military specifications are used almost exclusively in procuring paint materials for Government work. Paints received from the General Services Administration (GSA) receive limited testing, because of limited funding, and some are accepted even though they do not fully meet all test requirements. Testing at the Army's Construction Engineering Research Laboratory (CERL) and the Naval Civil Engineering Laboratory (NCEL) indicate that no more than half the paints procured directly from paint suppliers conform completely to specification. Actually, paints provided by contractors are more often accepted as conforming to specification rather than tested.

Federal standards and specifications for paints and other materials are updated periodically by GSA or assigned agency or command. In order to further increase competition, the present Government policy is to modify the specifications to allow a wide latitude in formulation as long as the desired properties are received in the final product. However, it is much more difficult, time consuming, and expensive to conduct performance tests to define these properties than to conduct the compositional tests previously used.

Navy inspectors for contract painting have limited time, training, and equipment to assure that all provisions of the specification are met. They are usually inspecting six or more contracts at one time, obtaining the necessary information to go into the inspectors daily reports.

GOALS OF ACCELERATED TESTING OF PAINTS

It is the goal of the NCEL investigation of accelerated testing of paints to develop simple, rapid test procedures that will assure that quality paint products will be applied to properly prepared surfaces in a manner that will

provide long-term, cost-effective protection of Navy structures. In order to meet this goal, three basic types of accelerated tests are required:

- Laboratory tests that will assure that quality paints formulated for long-term performance are procured.
- Field tests that will permit inspectors with limited training to detect products with inferior quality.
- Sophisticated tests that will assure that the paints have been properly applied to substrates as necessary for long-term protection.

LABORATORY TESTS FOR QUALITY PAINTS

Present laboratory accelerated tests for paint performance (e.g., salt fog and other chamber tests) correlate rather poorly with actual field performance. The NCEL approach to obtain early (a few weeks) data is to accelerate natural deterioration and measure early signs of paint deterioration. Methods such as AC impedence measurements may provide information not only on coating deterioration but also underfilm corrosion. Early data will be treated mathematically, so that predictions can be made of performances in various environments. This can then be used to determine which paint system will be most economical for a particular purpose.

FIELD TESTS FOR PAINT QUALITY

NCEL has developed for CERL a prototype test kit with simple procedures for a paint inspector to rapidly detect suspicious paints that should be checked in a laboratory before use. To date, the test procedures apply only to latex and oil-based paints (common house paints). NCEL is extending the technique to include high performance coatings that can provide more economical protection. Also, an attempt is being made to accelerate the tests so that no more than 2 days will be required.

FIELD TESTS FOR PAINTED SURFACES

Tests that will define the condition of painted surfaces cannot only determine if quality application has occurred but can also indicate how much service life is left and what maintenance actions may be necessary to obtain maximum life.

Tests will be needed to determine such properties as paint adhesion, permeability, extent of weathering, and underfilm corrosion. It is ancitipated that some of the laboratory tests developed in the test procedures for quality paint will be applicable in this portion of the investigation. Thus, AC impedence techniques may be modified to meet needs. In other cases, entirely new equipment must be developed.

CURRENT TECHNICAL NEEDS

As indicated above, the chief need from industry or elsewhere is equipment and techniques for measuring early changes in paint films that can be correlated to actual field performance. These techniques may involve such technologies as adhesion, film permeability, ultrasonics, radioisotope procedures, infrared

spectroscopic measurement of polymer changes, or totally different approaches. It is only from a cooperative effort that there can be developed accelerated paint testing procedures that will prove to be cost effective to the Navy as well as to private industry.

ACKNOWLEDGEMENT

This effort is being sponsored by the Naval Facilities Engineering Command, Alexandria, Va.

IN-SITU THERMOCONDUCTIVITY MEASUREMENTS

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The concept for this device was initially developed because there was a need for a device that could measure thermal conductivity using inexpensive sensors that were readily available from commercial sources, required no specialized instruments, and was field operable. The measurement technique that resulted uses a commonly available thermistor as a sensor, a few simple mathematical equations, and a simple circuit such as the one shown below in Figure 1. One complete measurement of thermal conductivity takes approximately twenty minutes and all necessary calculations can be completed using a hand held calculator. Since this technique measures thermal conductivity at a single point, a statistically valid sampling technique must be used to obtain an average value for the thermal conductivity of a non-homogeneous material.

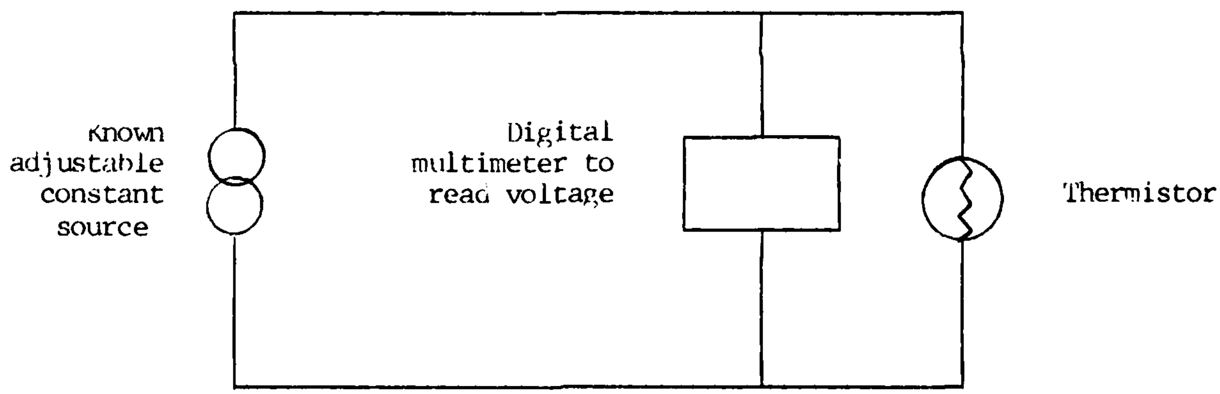

Figure 1: Circuit Used in Thermoconductivity Measurement

There are specific restrictions on the use of this measurement technique. There must be sufficient material to ensure that measurements are taken in a large volume compared to the volume of the thermistor. The material must have a reasonably uniform temperature distribution that is relatively stable and its grain size must be small enough to **ensure** that intimate thermal contact is maintained over the entire surface of the thermistor. Some examples of materials for which this measurement technique is appropriate are fine grained soils, building materials such as polystyrene, gel-like materials such as silicone grease and fibreglass insulations. Applications for which this measurement technique has some unique characteristics are profiling insulations that have absorbed moisture,

monitoring building insulations to detect moisture penetration and measuring soil samples obtained in drilling operations.

Currently, a microprocessor based instrument is being created to simplify the measurement procedure even further. Operating this instrument will entail inserting the thermistor into the material and pressing a button. Fifteen to twenty minutes later, the thermal conductivity of that material will be displayed.

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Ronald T. Atkins, U.S. Army Cold Regions Research & Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755-1290.
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Nondestructive Evaluation of Pavements

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The Waterways Experiment Station, CE, has developed and implemented nondestructive pavement evaluation methods for both airfields and roads and streets. Research in this area has resulted in equipment development, test and survey techniques, and analytical methods. The total pavement evaluation process involves (1) a condition survey of the pavement surface to identify and measure observable distresses, and (2) a structural rating (load capacity) as measured with specially designed test equipment that use nondestructive, dynamic load tests.

Surface Condition Evaluation

The surface condition evaluation uses the pavement condition index (PCI) procedure. This method involves measuring observable surface distresses, applying weighting factors (deduct values) to each distress, and computing an overall surface rating from a scale of 0 to 100. This PCI procedure is described in several published reports.[1-5] The PCI method is an objective rating method based on measuring the quantity and severity of each distress type present in the pavement. Distress types and definitions are slightly different between airfields and roads. The PCI method was developed by correlation of distress measurements on in-service pavements to the subjective rating and collective judgement of a group of pavement engineers.

The PCI measures the existing condition of the pavement and is an indicator of how it has performed to date. The distress types have been categorized as to possible cause. Maintenance history has an influence on the PCI rating, and the PCI generally increases with completion of maintenance operations. The PCI is used to select maintenance alternatives and is a key element in the PAVER Maintenance Management Program.

Nondestructive Structural Evaluation

A large vibratory test device called the WES 16-kip vibrator was designed and fabricated by the Waterways Experiment Station in the late sixties.[6] This machine, which is contained in a semitrailer, applies a steady-state vibratory loading to a pavement. An analytical methodology was developed for structural pavement evaluation by correlation of measurements of this device with results from conventional test pit methods. The measurements made by the WES 16-kip vibrator for use in this method are (1) dynamic load applied through an 18-inch-diameter steel plate on the pavement surface and (2) vertical surface deflection measured on the plate with electronically integrated velocity transducers. Tests are performed at 15 Hz, although the machine capability allows operation at frequencies of 5 to 100 Hz. A ratio of the measured load to deflection termed the DSM (dynamic stiffness modulus) is used to predict allowable load on a specified single wheel. This load (using factors for gear geometry and repetition levels) can then be translated to allowable load on any aircraft at specified repetition levels.[7] Additionally, overlay thickness requirements for any specified loading condition can be computed. This DSM method has been adopted by the Federal Aviation Administration as its standard

method for nondestructive airfield evaluation.[8,9] It is also the method used for routine evaluation of Army airfield pavements.[10,11]

For Army road and street pavements a similar methodology has been developed using a Road Rater Model 2008 test device. The Model 2008 is similar to the WES 16-kip vibrator in principle of operation and type of data measured. Its dynamic load output is approximately one fourth of that of the WES 16-kip vibrator.

New developments in nondestructive pavement testing include the use of the falling weight deflectometer and layered-elastic analysis. The falling weight deflectometer has the advantages of being more transportable, lighter weight, and requires fewer operational personnel. The layer-elastic analysis provides for calculation of the elastic moduli for pavement layers and subgrade based on deflection measurements at the pavement surface. This analysis is device independent and will analyze measurements from any of the NDT devices that measure deflection basins. A weak layer in the pavement structure can be identified by this method (not true for DSM method). Computer programs have been completed for the layer-elastic method and are available for application on the IBM personal computer.

All of these NDT evaluation methods developed by the Waterways Experiment Station have been verified through comparisons with traditional test pit methods.[13] All of the analytical methods have been documented and computer programs for each method have been prepared.

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SLIP RESISTANT REFLECTIVE FLOOR COATINGS

by
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The Navy and the Air Force use reflective coatings in aircraft maintenance hangars to increase the illumination at the underside of aircraft. The coating systems typically used consist of chemically resistant urethane (CRU) topcoats, an epoxy primer, and grit that is incorporated in the topcoats to provide slip resistance. These coatings currently cover about 5 million sq ft of the Navy's 13 million sq ft of maintenance hangars, and their use is increasing. The Air Force and the Air National Guard have much greater areas of maintenace hangars, many of which are coated.

The reflective coatings are effective in improving underside illumination of aircraft, which is increased about fourfold. They then meet their goal of improving aircraft maintenance and of providing safer aircraft. The chief problem with these coating systems is that they are often unsafe for maintenance personnel, because they may become very slippery. The slipperiness is increased when hydraulic fluid or oils are spilled on the floor. With residual oily products or detergents on the floor, even water may produce a very slippery surface.

What the Navy requires is a reflective floor system that is more permanent, has good reflectance, has good slip resistance, and is easy to maintain. Also needed is a good method of measuring the dynamic slip resistance of the floor, and a standard slip resistance requirement.

Most of the currently available coating systems for hangar floors use alumina grit, approximately 30-mesh, that is broadcast onto the wet first topcoat. The grit is then overcoated with a second 2-mil topcoat to produce a system typically about 7 mils thick, exclusive of the grit. The large grit is easily removed from the comparatively thin topcoat in normal usage, which includes some dragging of equipment across the floor. About half the grit may be lost in one year, and the floor may become objectionably slippery in a year or two. The main reason for recoating maintenance hangars is the loss of grit that results in slippery floors.

A major problem with the above-described coating systems is the difficulty in applying the grit in a uniform manner. Typically a small lawn seeder or fertilizer applicator is used, but if this is not skillfully used, a very uneven application may result. Some areas of the floor may thus have high slip resistance and others may have low slip resistance. Such a situation tends to be more hazardous than an area of uniform low slip resistance.

More uniform grit distribution can be accomplished by premixing the grit in the wet coating before application. Because alumina is much denser than the coating, 80-mesh is the largest size that can be suspended well enough for application by roller. Polypropylene grit is less dense than the coating, and the 60-mesh material (which appears to be the largest that is readily available) can be premixed well. A 100-mesh polypropylene has also been used with good preliminary results. (Sand or quartz are crushed too easily on the floors and have not provided good performance.)

Laboratory studies indicate that a second overcoating of the currently used 30-mesh grit would appreciably reduce the loss of grit. Using twice the amount of 46-mesh alumina (about 6 lb/1,000 sq ft instead of the 3 lb/1,000 sq ft typically used) and overcoating with two 2-mil topcoats should give even longer performance with lower but still acceptable slip resistance. The following are the current indications for the best use of CRU topcoats after the application of grit:

30- or 36-mesh alumina:	Two topcoats
46-mesh alumina:	Probably two topcoats
60-mesh polypropylene:	One topcoat, possibly with premixed grit
100-mesh polypropylene:	One topcoat with premixed grit

Most of the coating manufacturers consider their systems to be very flexible, and they will often leave the choice of the amount, type, and placement of grit up to the customer. They may suggest a coating without grit for easier cleaning where slip resistance appears to be of little concern, or they may suggest more grit than necessary where slip resistance appears to be of great concern. Instead of the manufacturer taking responsibility for the complete system and its long term performance, the choice of the method of providing slip resistance is left to the more inexperienced user.

There are two current alternatives to the reflective CRU coating systems described above. Epoxy toppings with embedded grit (about 0.25 inch thick) are available that could be overcoated with a reflective CRU topcoat. Such topping systems would be about twice as expensive as the CRU coating systems. Although it should be possible to design such topping systems to outperform the CRU coating systems, little practical performance information is available.

A second alternative is reflective concrete. This is not a coated floor but is a monolithic concrete, or a topping at least 2 inches thick, finished with a dry shake. If properly installed, it lasts more than 20 years, but it is very smooth and objectionably slippery when wet or oily, and therefore not recommended for Navy use. Currently there is no method for producing a textured surface that retains the light reflective capability and the wear resistance.

An improved coating system for which the manufacturer takes complete responsibility, or either of the two alternatives, properly modified, might satify the Navy's requirements for an effective reflective flooring. A sled-type slipmeter has been developed by the Naval Civil Engineering Laboratory, which could serve as a basis for improved slip resistance measurement techniques.

This research work has been sponsored by the Naval Facilities Engineering Command, Alexandria, Virginia.

UNDERGROUND OBSTACLE DETECTION

by
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The Navy implements an estimated 2,000 contract change orders for $21,000,000 annually because unexpected underground objects are encountered during construction excavations. An additional $1,000,000 is expended to administer these change orders. Contract change orders arise largely because of inaccurate and incomplete drawings prepared through contracts with A&E consulting firms. These drawings are inaccurate because of the lack of effective methods to collect the required underground data. A surveying system is needed to collect data such that accurate and complete drawings of the Navy's underground facilities can be prepared prior to awarding excavation related contracts.

Because of the recognized need, the Naval Civil Engineering Laboratory (NCEL) was tasked to pursue the development of an underground obstacle detection system. Initial efforts have been directed at performing benefit cost analysis and determining parameters that affect the performance of ground penetrating radar signals. The results of these investigations show that when operational, the development and procurement cost of the required system will be easily recovered in less than a year and will result in considerable cost savings to the Navy.

To meet Navy needs, the required system must have the following capabilities:

1. Detect more than 90% of metallic and nonmetallic objects of sizes ranging from less than 1 inch to 5 feet or more through the entire ground profile to the 20-foot depth to which underground utility lines are buried. The ground profile may consist of a pavement at the surface and sublayers of various types of soils including clays of high moisture content.
2. Locate such objects accurately in terms of x-, y-, z-coordinates to a precision of ±1/2 foot.
3. Record survey data automatically in a format that is machine processable for conditioning as input to computerized drafting systems (e.g., Computervision) to quickly produce drawings of the surveyed area including the underground objects, and where the survey information can be stored in a database for future project requirements.
4. The survey system is operable by a maximum of two persons - an electronic technician and a civil engineering technician.
5. The targeted cost of the equipment should be less than $115K per unit.

To determine present state-of-the-art detection capabilities, three ground penetrating radar (GPR) systems and seven hand-held detection devices were tested at a Navy construction site. Evaluation of two of the three GPRs were conducted through contracts with the manufacturers who operated their equipment, interpreted the data, and submitted their results to the Navy. The third GPR was an Army modified and operated unit that was previously purchased from one of the two manufacturers who participated in the study. The hand-held devices were those that the Army considered the most effective based on their evaluation tests.

Results of NCEL's investigation of the three GPRs and seven hand-held detectors are summarized in Figure 1. The results show that GPR systems are superior to the other detection devices because they are able to detect both metallic and nonmetallic objects. However, at best, present GPR detection capabilities are such that only 60% of metallic and 36% of nonmetallic objects are detected. Factors that cause this poor performance of GPRs included insufficient penetrating power, insufficient signal processing, and deficiencies in data reduction. Problems with data reduction include not being able to discern the location of the ground surface on the records (it is obliterated by the transmitted source signal pulse and ground surface reflection effects), the use of inappropriate factors to caclulate the depth of each target, and the difficulty in identifying actual targets and their locations on the records due to clutter and noise. These manual data reduction methods, including calculations and visual interpretation of the records, create inadequate and poor results. Machine processing software i. required to facilitate record interpretation.

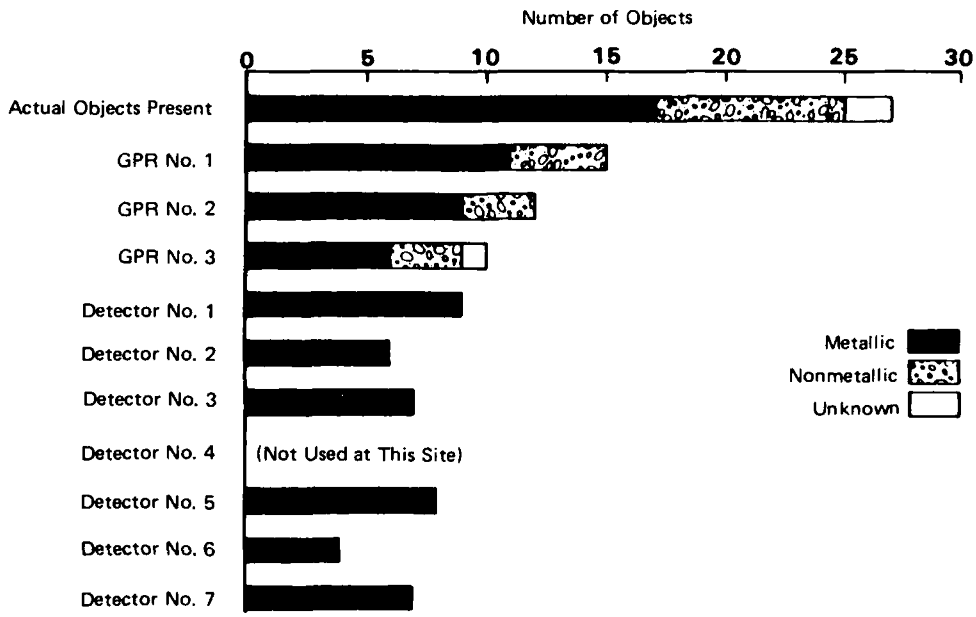

Figure 1. Test results of ground penetrating radars and detectors.

Because GPRS can detect both metallic and nonmetallic objects, ground penetrating radar is considered by us to have the best potential for meeting the surveying needs of the Navy. The development of such a system is, therefore, being pursued. Development efforts currently underway include high powered-focused antenna, evaluation of impulse/step/swept frequency for optimum GPR source signal for obstacle detection, and signal processing-image reconstruction software. Subsequent planned efforts include design, fabrication, and evaluation of an experimental GPR, development of a test site, and development of software for interfacing GPR data with computerized drafting systems.

ACKNOWLEDGEMENT

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Repairing Concrete with Polymers

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The use of polymers for repairing concrete has increased greatly since the early 1950's when they were first introduced for this purpose. This increase is due to the development of new systems and to the many desirable properties that polymers can possess. Polymers for repairing concrete may be used without fillers or aggregates, or as binders for mortar or concrete containing aggregates. Polymer concrete (PC) is a composite material formed by polymerizing a monomer incorporated as a binder in a mixture of fine and coarse aggregate. Polymer-portland-cement concrete (PPCC) is a premixed material in which either a monomer or polymer is added to a fresh concrete mixture. When latex (an emulsion of polymer and water) is added to a fresh concrete mixture, it is often referred to as a latex-modified concrete (LMC).

Many different polymers are used to repair concrete; the most popular is epoxy resin. This is because of the many physical properties that can be obtained from epoxies, good adhesion to concrete, long-time experience, and availability. Other polymers that are used and are available commercially include acrylics, polyesters, vinylesters, polyurethanes, styrene-butadiene, and polyvinyl acetate. There are additional commercial products available which contain other polymers not mentioned above.

Epoxy resins are used as an adhesive to bond freshly mixed concrete to hardened concrete, and for bonding other materials to concrete. This polymer is also used for grouting bolts and dowels into concrete, repairing cracks by pressure injection, as protective coatings, and for spall repair. LMC are used as thin overlays (1/4 to 1 1/2-inch) for concrete and as patching materials. The acrylics are used as protective coatings and as a binder for PC used in the repair of pavements. Polyesters, the least expensive of the thermosetting resins are used as protective coatings. Polyesters have been used to overlay bridge decks. Polyurethanes have also been used for protective coatings because of their high abrasion resistance. Polyurethane chemical grouts are now being used to stop water leakage in hydraulic structures.

The Waterways Experiment Station (WES) has been involved since the late 1950's in the testing and evaluation of polymers used to repair concrete. The latest completed program was the Facilities Technology Application Tests Program in which WES demonstrated some of the latest technology in using polymeric systems to repair concrete. Two army facilities were selected for the demonstrations: Fort Bragg, North Carolina and Fort Ord, California. At Fort Bragg, the concrete footings around a water tower and a multi-story building were chosen for repair; at Fort Ord, the concrete roof decks of two water storage tanks were selected. The cracks and delaminated areas of the

footings around the water tank were repaired by injecting an epoxy resin under pressure. The building repairs consisted of sealing cracks and repairing overhead and vertical spalled areas. The cracks were routed out and sealed with a polyurethane joint sealant. The spalls were repaired with a commercial LMC. The two concrete roof decks repaired had the same problem, spalling due to the corrosion of the reinforcing steel. The method chosen to repair these roof decks consisted of:

a. Removing unsound concrete in the spalled areas and exposing the reinforcing steel.

b. Cleaning the entire roof deck and exposed reinforcing steel by sandblasting.

c. Patching all spalled areas with polyester mortar.

d. Covering the roof deck with a thin 3/8-inch coating of a polyester concrete after sealing with a neat polyester resin. A thin coat was necessary because some of the roof decks sagged and any additional mass had to be minimized.

e. Removing the old joint sealant material and replacing it with new material.

Programs now ongoing at WES in which polymers are being evaluated include: The Repair, Evaluation, Maintenance, and Rehabilitation Research Program (REMR) and The Repair of Airfield Pavements with High Molecular Weight Methacrylates (HMWM). Numerous polymer materials for patching concrete, repair of cracks, surface treatments, and for in-situ repair are being evaluated for the REMR program. Six HMWM were evaluated by WES for the Air Force and three of these polymers are being used to repair airfield pavements. Material and guide specifications for the HMWM are now being prepared by WES.

Acknowledgements

Program Title	Sponsor
Facilities Technology Application Tests, Concrete Repair	OCE
The Repair Evaluation Maintenance and Rehabilitation	OCE
The Repair of Airfield Pavements with High Molecular Weight Methacrylates	Air Force Engineering and Service Center

Transducers For High-Shock Environments

by

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The Department of Defense requirement to measure explosively-generated pressures, forces and motions to extremely high levels both in air and geologic media has resulted in the development of a family of rugged transducer systems. Some of the transducers have been developed to a fully operational level, whereas others require further refinement, development or verification. Current transducer technology falls within three general catergories: (1) dynamic airblast pressure; (2) dynamic soil stress; and (3) ground shock. Table 1 lists the current status of WES developed or employed systems.

AIRBLAST PRESSURE

THE CBA (Column-Based Airblast) gage is an extremely rugged (essentially solid hardened steel) cylinder designed to be flush-mounted only 5 or 6 inches from an explosive source. The gage performs well to about 50 ksi, withstanding both inertial forces on the order of several million "g's" and severe thermal gradients.

The WBG (WES Bar Gage) is a hardened 1 to 2 inch diameter circular steel rod flush-mounted as with the CBS Gage. Gage lengths range from about 10 to 20 feet. Relatively long rods are required to enable adequate signal capture prior to distortions introduced by the reflected signal from the bottom of the bar. Good early-time data are produced. The pressure-time signal is integrated to derive impulse data. A disadvantage of this gage is the short undistorted data time base (0.5 msec for the 10 ft bar length; 1.6 msec for the 20 ft bar length). A numerical data unfolding technique is under development which will allow extention of the usable data out through several reflection cycles.

SOIL STRESS

Free-Field - Three gage types are used to measure free-field soil stresses. The SE gage, the CBS (Column Based Stress) gage, and the SRII developed Flatpack.

The SE gage is a wafer-shaped double, symmetrical diaphram-type transducer. Both top and bottom surfaces are active sensors. The gage is commercially available from Kulite Semiconductor, Inc. Ridgefield, NJ. Three pressure ranges are available: (1) 0-200 psi; (2) 0-5 ksi; (3) 0-10 ksi.

The CBS gage is similar in design and function to the CBA gage. The present version has been verified for measurement up to the 50 ksi level and has been certified for commercialization.

The Flatpack gage was developed by SRII and is being evaluated by WES (and other agencies). It consists of a piezoresistive sensor of either Ytterbium, manganin, or carbon, depending on the desired upper pressure bound. The sensor and signal lead wires are encased in a long (several feet) welded flat steel shell for protection. Measurements are routinely made up to the 10 kbar stress level and can theoretically be measured to levels exceeding 50 kbar. The gage is available on special order.

The CBI (Column Based Structure Interface) gage is similar to the CBS gage. It is designed to be cast into prototype or model structures/structural components with the sensing face flush with the outside surface of the structure in order to measure soil stress loads against the structure. Measurements are made to the 25 ksi level. The present design does have a relatively high transverse (cross-axis) sensitivty which is undesirable.

PARTICLE VELOCITY

There is no particle velocity gage capable of measuring velocities above 60 ft/sec. The extraordinary acceleration fields associated with large particle velocities generated by explosions require isolation from the incident pulse accelerations. A successful approach has been the use of a mechanical isolator system to absorb/retard the initial acceleration (on the order of >250 kg). The SIA (Shock-Isolated Accelerometer) uses either a relatively soft elastic isolator (nylon reinforced neoprene) or a crushable encapsulant (foam cement). The output acceleration-time signal is integrated to derive velocity-time data.

TABLE 1. High-Shock Transducer Nomenclature

Parameter	Transducer (Developer)	Operating Principle	Operational Range [Design Range]	Advantages	Disadvantages	Status
1. Airblast Pressure	CBA (WES)[a]	Strain Gaged Load Column	5-50 ksi [>100 ksi]	Relatively long data capture time	Somewhat degraded initial/early time fidelity	In-Development
	WBG (WES)	Strain Gaged Long Cylindrical Bar	1-90 ksi [>200 ksi]	Excellent initial/early time fidelity	Short data capture time	In-Development
2. Soil Stress						
a. Free-Field	SE (WES)	Strain Gaged Diaphragm	0-10 ksi [10 ksi]	Small, easy to place, commercially available[b]	Usable only to lower pressures	Fully-Commerical-ized
	CBS (WES)	Strain Gaged Load Column	2-50 ksi [>100 ksi]	Excellent early to long time data fidelity	Present operating range needs to be extended to at least 100 ksi	Certified for commericalization
	Flatpack (SRII)[c]	Ytterbium, Manganin or Carbon Sensor	1-10 kb [>50 kb]	Extremely rugged, highest range available, long time data capture	Requires pulse power, complicated data unfolding	In-Development (available for special order purchase)
b. Structure-Interface	CBI (WES)	Strain Gaged Load Column	1-25 ksi [>50 ksi]	Small, rugged, fast response, can be cast in structures	Somewhat sensitive to structure transmitted cross axis loads	In-Development
3. Particle Velocity	SIA (WES)	Shock-Isolated Accelerometer	0-150 ft/sec (10-250+ Kg) [>300 ft/sec] [(>1Mg)]	Withstands extreme initial shock loads to capture low level particle velocity	Inital data is distorted	In-Development

a WES = U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS
b Available commercially from Kulite Semiconductor, Inc. Ridgefield, NJ
c SRII = Stanford Research Institute International, Menlo Park, CA

ROOF BLISTER VALVE

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U.S. Army Cold Regions Research and Engineering Laboratory

Annually, the Army spends about \$70 million on maintaining and repairing its built-up roofs. Blisters account for much of this expense.

Blisters significantly increase the likelihood of roof leaks. If they remain small and intact, there usually is no problem. Larger ones, however, are susceptible to damage, such as from foot traffic and increased weathering. And once damaged, water can enter. Even if blisters do not leak, they can affect a roof's performance in other ways. They usually occur between the plies of a built-up membrane and, because of this, act to weaken the membrane, making it more susceptible to splits. Blisters can also contribute to the general deterioration of a roof by affecting drainage patterns and creating ponds.

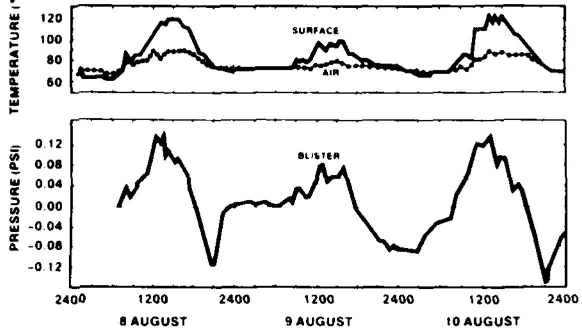
Causes of Blisters

Recently, studies were conducted to determine the causes of roof blisters and to develop new approaches for dealing with blisters. The studies involved pressure measurements and visual examinations.

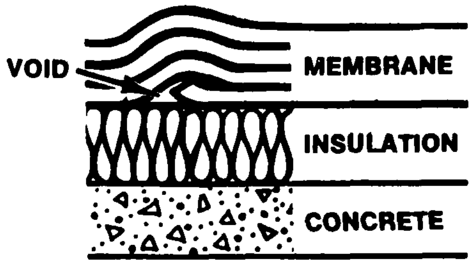
The pressure measurements revealed much about the mechanics of a blister. As shown below, internal blister pressures vary from positive during the heat of the day to negative during the cool of the night, which explains why blisters grow. Air is drawn into the blister at night and, when exposed to sunshine, rapidly expands before it has a chance to escape. This causes a pressure rise resulting in growth.

Many people feel that water is necessary to cause this growth. By assuming that a blister is a sealed and rigid container, its internal pressures can be calculated. For example, moist air, when heated from 70° to 100° F, increases in pressure by about 1.4 psi. Dry air increases by 0.8 psi. Both of these calculated pressures are considerably higher than the pressure increases shown below. Clearly, water vapor is not needed to pressurize a blister.

Visual examinations suggest that most blisters are built into a roof. Defects such as skips in the bitumen, entrapped debris, bitumen bubbling, and curled interply felts all suggest that better design and workmanship could prevent many blisters. However, because a built-up membrane is so difficult to fabricate even under the best conditions, some blistering is likely.

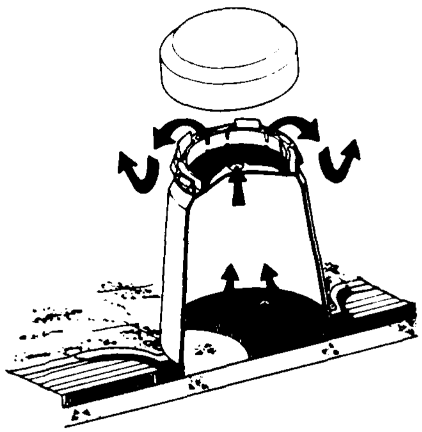


Blister pressure measurements.



Curled felt resulting in a void.

Cutting open a blister.



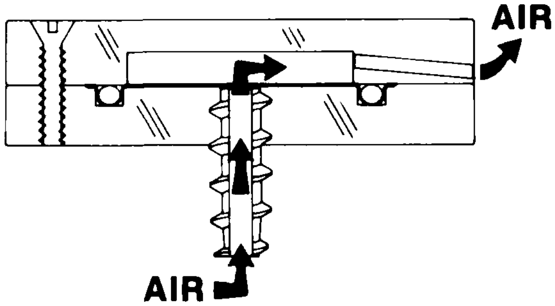
Roof breather vent.

Current Practices

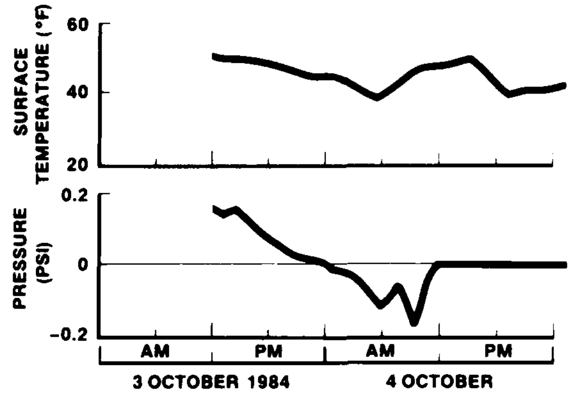
Currently, few options are available for dealing with blisters. One approach is to cut each blister open and patch it. This approach, however, is generally not used until a blister breaks. This reluctance to do anything until a problem occurs stems from the fact that this repair method is slow and tedious. Also great care must be taken to not entrap air pockets within the patch, which would create a new crop of blisters.

Roof breather vents are promoted as another means of eliminating blisters. However, most blisters occur between the membrane plies or between the membrane and the impermeable insulation facing below. Such vents do not affect these blisters because the vents communicate only with the insulation layer. Roof breather vents do not prevent membrane blistering.

Therefore, doing nothing until problems arise is the currently accepted practice of dealing with blisters.



Pressure valve.



Zero pressure after valve.

New Approach

Rather than wait until a blister breaks, a miniature pressure relief valve was built with the purpose of stopping blister growth. As shown above, the valve consists of a hollow shaft covered by an air permeable/water impermeable membrane protected by an environmentally tough housing. Its small size, 1 1/2 in. diam. x 1/2 in. high, makes it very resistant to damage from foot traffic and, once inserted, blister growth is stopped. Typically, as seen above, no pressures develop after a valve is installed in a blister.

These valves will be demonstrated on a 2-year old, six acre, blister-filled roof this summer (1986).

Status

--A report describing recent blister studies is in draft form and should be available during the winter of 1986.

--An application for Army patent rights has been filed.

--The roof blister valve offers distinct possibilities of economically, effectively and efficiently dealing with blisters before they become a problem.

--The device is ready for commercialization.

For additional information, contact the author at CRREL, 72 Lyme Road, Hanover, NH 03755. Telephone (603)646-4100.

Ceramic Anodes for Cathodic Protection

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ABSTRACT

Ceramic anodes developed and patented by USA-CERL have been installed in impressed current cathodic protection systems for water storage tanks, buried pipelines, and waterway projects. The initial ceramic anode consisted of a lithium ferrite coating plasma sprayed onto hemispherical shaped niobium or titanium substrates. An exclusive license to manufacture the ceramic anode was recently awarded to APS Materials, Inc. of Dayton, Ohio. USA-CERL in conjunction with APS Materials is currently working on new mixed metal oxide anode materials and designs to lower costs and further minimize ice and debris damage to the cathodic protection system. A number of ceramic anode and cathodic protection designs will be presented. In addition, future technology needs such as low maintenance anode/rectifier combinations will be identified.

INTRODUCTION

For the past 30 years, two materials--silicon-iron and graphite--have been used in the cathodic-protection anode. However, these materials are brittle and have consumption rates on the order of one pound per ampere year; i.e., if one ampere of current is passed through the anode for one year, one pound of the anode will be consumed. Consequently, large anodes (weighting up to 60 lbs or 27 kg's) were required, which made the anode vulnerable to debris/ice damage and also prone to field installation problems. The possibility of using electrically conducting ceramics for anodes in cathodic protection was investigated by USA-CERL, since the consumption rate of conducting ceramic materials such as ferrites is 500 times less than silicon-iron and graphite anodes.[1,2,3] However, ceramics are extremely brittle and cannot be fabricated. To overcome these problems, USA-CERL plasma-sprayed ferrite on valve metals (titanium or niobium) which can be fabricated in any shape. This resulted in an anode that is much smaller (500 times by weight) with a low dissolution rate.

Figure 2 shows the design for the mixed-metal oxide coating, titanium substrate anode. The critical anode to lead wire connection is factory fabricated and tested, eliminating related field assembly and installation difficulties.

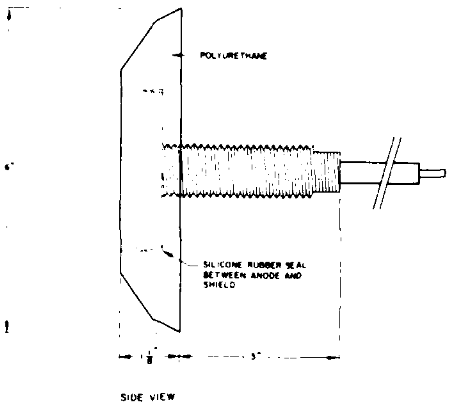

Figure 3 - Protective shield for flat ceramic anode.

To further reduce the damaging effects of impacts, a protective shield for the flat mixed-metal oxide anode was developed. The anode rests in the polyurethane plastic shield shown in Figure 3. While the shield leaves the coated anode face exposed, it protects the perimeter and the uncoated back of the anode from collisions.

CATHODIC PROTECTION DESIGNS USING CERAMIC ANODES

Test ceramic anodes were installed at the Racine Lock Gate structure on the Ohio River in West Virginia and at Miller's Ferry Lock Gate on the Alabama River. Inspection of the test ceramic anode after more than two years of exposure showed no evidence of damage to either the cable or the ceramic coating. The ceramic anode was found to be passing 50 m/A of current. Cathodic protection systems incorporating the new flat and rod type ceramic anodes will be installed at these same locations and also at Cordell Hull Dam, in Tennessee.

CERAMIC ANODES

Plasma Sprayed Ceramic Anode

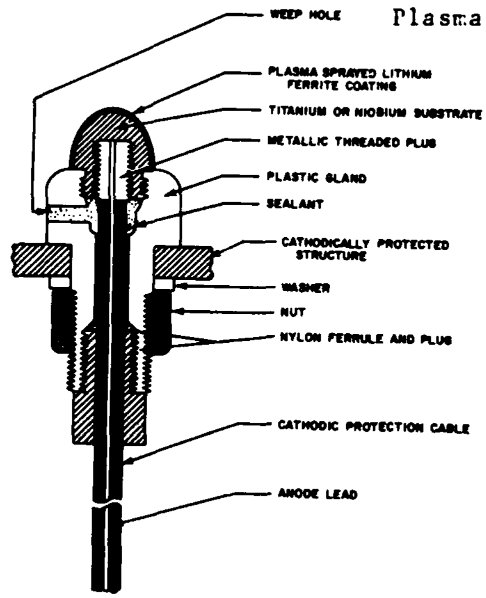

Figure 1 - USA-CERL Plasma sprayed ceramic anode

The configuration of the plasma sprayed ceramic-coated anode is shown in Figure 1. It consists of a 20-mil (0.05 cm) to 50-mil (0.12 cm) thick lithium ferrite coating deposited on niobium or titanium substrate. The metal substrate is machined to a button shape, 1 inch (2.54 cm) in radius, and threaded to fit a plastic gland. The critical anode-to-cable connection, traditionally prone to failure, is made at the factory rather than in the field. Anode installation is accomplished by drilling a hole in the structure and attaching the anode assembly with a nut and washer. Weight loss measurements after a 2-month test in 3.5% NaCl solution showed the dissolution rate of the plasma sprayed ceramic-coated anode to be only 1.7 grams per ampere year at a current loading of 2000 amperes per square meter.

Flat Anode Design

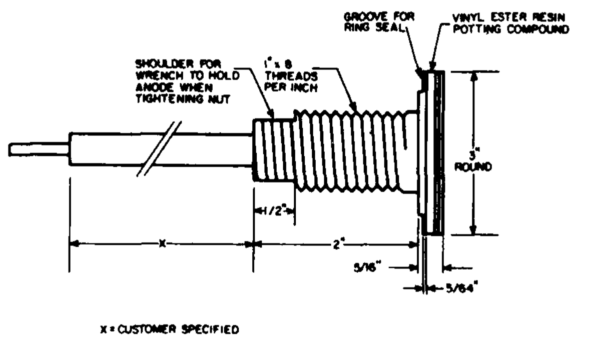

Figure 2 - Flat ceramic anode

A new flat anode has been developed that would minimize ice and debris damage as well as machining costs which consists of a titanium plate with a mixed metal oxide coating. Two types of flat anodes were developed for fresh water and saltwater application. The ruthenium oxide/titanium dioxide coating, which is stable in the presence of chlorine was chosen for saltwater applications. The iridium oxide/titanium dioxide coating was applied to a titanium substrate to yield an anode suitable for use in fresh water and soil. Metal oxides such as ruthenium and iridium oxides (RuO_2 and IrO_2) are known to exhibit metallic electrical conductivity over a wide range of temperatures.[4] The main advantages of fabricating anodes from these materials are their very low resistivity (0.001 ohm-cm) and their very low dissolution rates (0.001 g/A/yr at 11 A/M^2).

Elevated Steel Water Tank

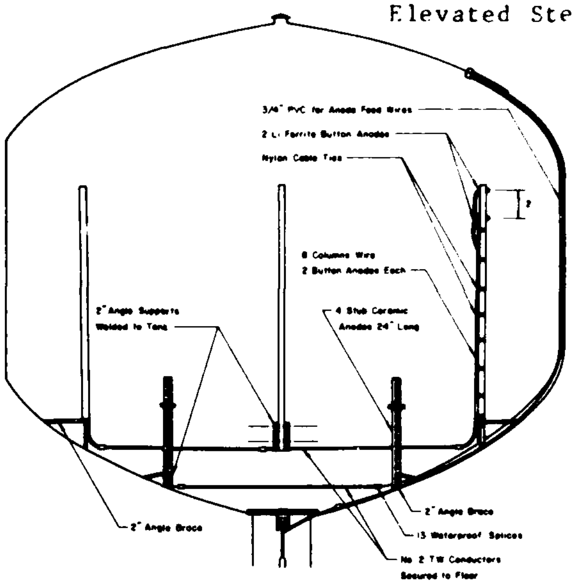

Figure 4 - Design and placement of ceramic anodes within a water tank.

A demonstration cathodic protection system using ceramic anodes was designed and installed for a 250,000-gallon (946 KL) ice free elevated steel water tank located at Fort Ord, California as shown in Figure 4. The tank dimensions are: height from the ground to the bottom of the bowl, 70 feet (21.3m); bowl height, 36 feet (10.9m); diameter of bowl, 40 feet (12.2m); and maximum water level in the tank from the bottom, 29.5 feet (9.0m).

A total of 16 button-shaped ceramic anodes and four stub anodes were determined necessary to cathodically protect the bowl.

Underground Pipes

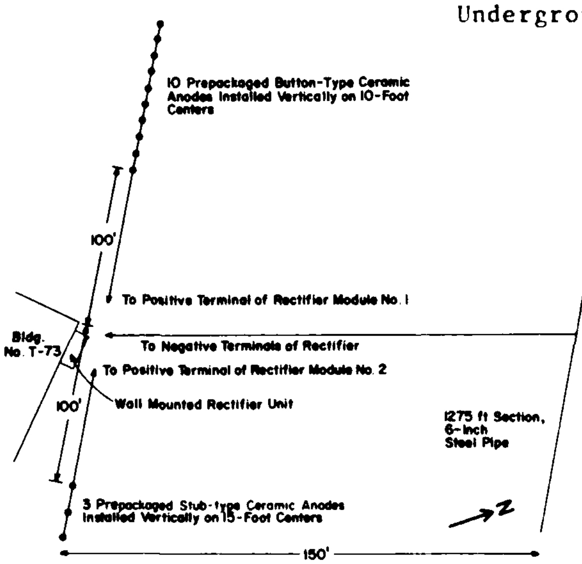

Figure 5 - Ceramic anode bed configuration for cathodic protection system of buried pipe at Ft. Monroe, Virginia.

A demonstrated cathodic protection system using ceramic anodes was designed for a 1275-foot (389m) long section of a 6.0 inch (15.2cm) diameter, underground steel pipe located at Fort Monroe, Virginia. The anode bed was designed to have two sections, Figure 5. One section contains 10 button-shaped, ceramic-coated anodes, while the other contains three stub-type anodes.

Each button-shaped, ceramic-coated anode and each stub anode was prepackaged in a canister containing extremely well-compacted, low-resistivity carbonaceous backfill. The status of the cathodic protection system is being monitored on a quarterly basis.

FUTURE TECHNOLOGY NEEDS IN CATHODIC PROTECTION

There is clearly a need to develop cost effective design criteria for a low maintenance cathodic protection retifier/anode single unit system and to provide real time monitoring of cathodic protection systems. The low maintenance rectifier/anode system incorporates both the rectifier and anode as a single unit and would provide a virtual maintenance free cathodic protection system which could be easily buried or immersed. With automatic monitoring of an existing cathodic protection system, the facility engineer can easily determine the status of both the anode and rectifier at any given time.

ACKNOWLEDGEMENTS AND POINT OF CONTACT

This study was conducted for the Directorate of Civil Works, Office of the Chief of Engineers (OCE), under CWIS 31204 (Corrosion Mitigation in Civil Works Projects). The research was conducted by the Engineering and Materials (EM) Division, U.S. Army Construction Engineering Research Laboratory (USA-CERL). The OCE Technical Monitor was Mr. R. Kinsell (DAEN-ECE-E). Dr. R. Quattrone is Chief of EM. COL Paul J. Theuer is Commander and Director of USA-CERL and Dr. L. R. Shaffer is Technical Director.

USA-CERL POC is Dr. A. Kumar, COMM 217-373-7235, FTS 958-7235, AUTOVON through Chanute AFB, or toll-free 800-USA-CERL (outside Illinois), 800-252-7122 (within Illinois).

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HEAT RESISTANT CONCRETE

by

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The Navy has more than 80 concrete aviation engine test cells (AETC) that are subjected to constant heat and water cooling from 3 to 5 engine tests per day. Each cell would cost nearly $5 million to build today and each requires from $30K to $200K per year to repair and maintain in good working condition. Since engine testing is vital to the Navy, Marine Corps, and Air Force, it is imperative that the AETC be able to endure constant heat up and cool down without constant repair, maintenance, and down time. A typical AETC cross section is shown in Figure 1.

The Naval Civil Engineering Laboratory (NCEL) has investigated, tested, and evaluated a number of materials that could be used as heat resistant liners in AETC to protect the concrete. Among the products are: (1) steel plates, (2) inorganic mineral fiber boards, (3) high temperature organic polymer coatings, (4) inorganic silicate sprayed coatings, and (5) high temperature ceramic like products known as refractories. Refractories include mortars, clays, concretes, prebaked sheeting, and fireclay brick. The most durable materials appear to be the refractory products, although NCEL has noted some deficiencies for use in military AETC applications.

The chief problems are: (1) expensive and labor intensive methods of securing insulating materials to the carbon saturated concrete wall, (b) heat curing refractory products in place, and (3) heat shock and deterioration associated with the harsh environment in the test cell. NCEL is presently testing various refractories using test setups similar to that shown in Figure 2.

Although refractory products can easily withstand the heat of the cell (in the 500 to 1,000°F range), they are not designed to withstand water-cooled shock, vibration, engine thrust, and acidic vapors from the engine. Water is sprayed through a perforated steel tube (called an augmeter or collander) in order to suppress smoke from the engine exhaust. The walls vibrate from the engine, and exhaust gases impinge upon the walls at 100 to 500 ft/sec. Nitric acid forms from catalysis of gases and combination with super heated steam, and sulfuric acid forms from oxidation of sulfur in the fuel and combination with steam. Both acids causes erosion of both steel and concrete materials in the AETC.

Any new materials considered for lining the AETC must be able to withstand the constant chemical and physical stresses described above, for a minimum of 1,000 cycles of heat up and cool down (water sprayed cooling), per year, for at least 10 years with little or no maintenance. The materials must not deteriorate from the water cooled sprays, must be acid resistant, must protect the underlying structural concrete and reduce the spalling or erosion problems, and must be cost effective in attaching to the concrete walls. Materials must not flake, or otherwise disintegrate or add to environmental pollution problems.

NCEL currently has both basic research and advanced engineering test and evaluation programs on refractory products. However, major improvements in refractory products or applications methods, as described above, would be welcome in our test programs.

ACKNOWLEDGEMENT

Work on refractory products is being sponsored by the Naval Facilities Engineering Command, Alexandria, Va.

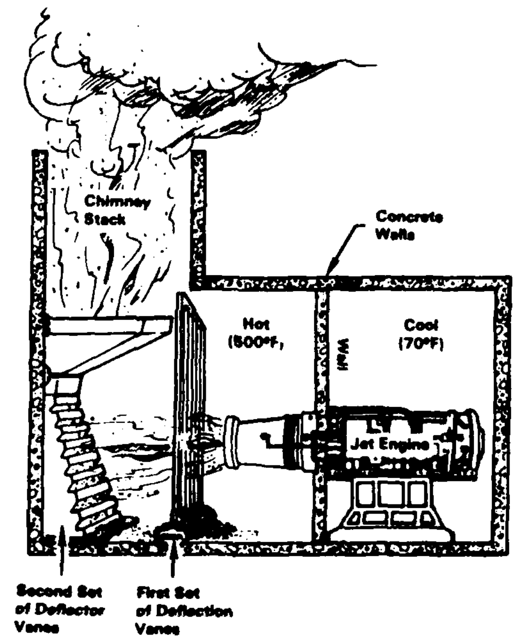

Figure 1. Type "C" jet engine test cell.

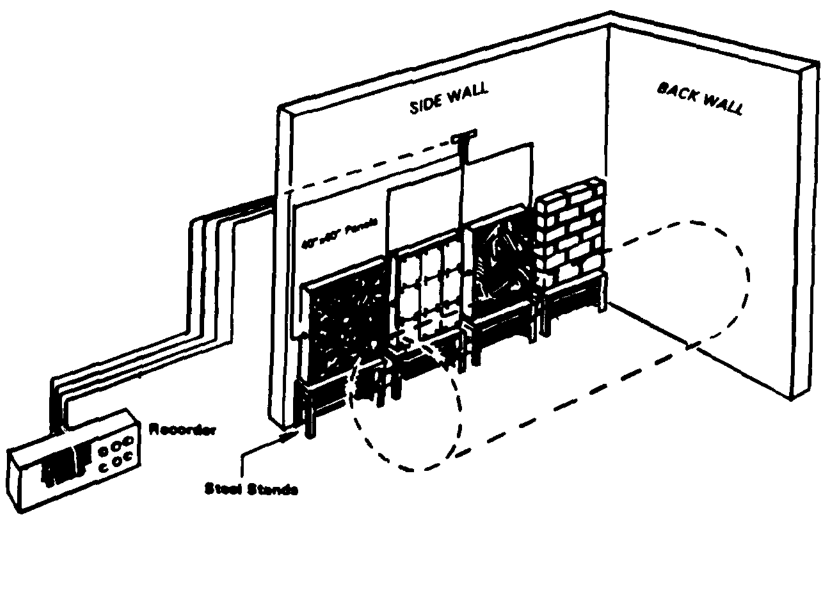

Figure 2. Location of test panels in engine test cell.

Needs in Roofing Materials

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ABSTRACT

The Army, Navy and Air Force are experiencing high maintenance and repair costs with low-sloped built-up roofs (BUR) at permanent installations. Reroofing contracts awarded by these services amount to more than $100 million per year. The problem is primarily caused by premature failure of BURs. The Air Force Strategic Air Command estimates that most of its "20-year design life" roofs last only 12 years, and that many roofs last only five years.

As a result of this poor experience, USA-CERL has been investigating the use of alternative materials for military roof construction. Funding for this research and its direction have been furnished by the Office of the Assistant Chief of Engineers, Facility Engineering Division.

Alternative roofing materials can be loosely cast into two categories: fluid applied and sheet applied. Fluid applied materials can be either sprayed onto the roof or applied with brush or roller. The most common applications of this type of roofing material are sprayed-in-place polyurethane foam (PUF) system with suitable elastomeric coatings, and the application of elastomeric coatings directly to concrete, shingles, or other suitable substrates. Sheet applied materials can be categorized as thermoplastic or thermosetting. Thermoplastic materials will soften or melt when heated, and will return to their original state when heat is removed. Thermosetting materials, once cured, are not affected by heat.

USA-CERL has been responsible for test applications of fluid applied and several sheet applied systems to date, and is planning further application of sheet applied systems in the future. Sprayed PUF systems were installed in 1980. Periodically, samples are removed from the roofs and are tested to determine changes in certain mechanical and physical properties. The tests indicate that the properties are all levelling off to constant values.

Two types of sheet-applied systems are also currently being tested: EPDM systems, a synthetic thermosetting rubber, were installed in 1980. PVC systems, thermoplastic sheet materials, were installed in 1982. These systems are also sampled periodically and tested in similar fashion. A side benefit to this work is the experience gained for making repairs to the system in case of accidental damage. Plans are already being formulated for furhter installation and testing of thermosetting materials such as chlorosulfonated polyethylene (CSPE, Hypalon) and polyisobutylene (PIB), and thermoplastic materials such as chlorinated polyethylene (CPE) and various

polymer-modified bitumens. In all cases samples will be taken from the roofs periodically and tested to determine changes in properties as the materials age naturally.

The construction phases of these investigations are documented in technical reports, and drafts of guide specifications are prepared based on the construction experiences. The guide specification is the ultimate Technology Transfer (T) document for field implementation of the research. Guide specifications for fluid-applied (PUF) and elastomeric thermosetting (EPDM) systems already exist. The guide specification for thermoplastic PVC systems has been written and is currently being reviewed by the industry. Guide specifications for other materials will be prepared in the future after the test roofs have been constructed.

These investigations are all directed towards studying the materials presently on the open market. They do not, nor can they, address the actual needs in roofing. These can only be addressed by the industry itself. They may be summarized as follows:

1. A system or systems for low-sloped roofs that can be easily applied without the need for highly skilled labor, are fool-proof in their installation, and will provide many years of trouble-free service.

2. Materials which can be repaired easily and permanently after several years of service, in the event of damage or deterioration, and methods for these repairs which are easily performed.

3. The expectation that all materials of a given generic classification will have comparable service lives, instead of the wide range of life histories that now exist.

HIGH-STRENGTH CONCRETE

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Background

1. Previous work has indicated that concrete with a compressive strength of 10,000 psi* is achievable with present-day technology and materials. Quality materials, use of a low water-cement ration (W/C), and admixtures are required. More recently the use of more effective admixtures, known as high-range water-reducing admixtures (HRWRA), and a very fine silicon-dioxide powder, known as silica fume, have shown promise for increasing the compressive strength of portland-cement concrete above 10,000 psi.

Purpose

2. The purpose of this work was (a) to conduct a study of the processes and techniques required to produce portland-cement concrete with a compressive strength of 15,000 psi or greater using conventional concreting methods and equipment, and (b) to develop physical property data on the mixtures.

Materials

3. Special materials and admixtures were permitted, but the emphasis was on use of readily available materials. Two coarse aggregates, a granite and a limestone, and two fine aggregates, a limestone and a natural silicon sand were used. Other materials were a Type II portland cement, a Class F fly ash, silica fume and two HRWRA's, one napthalene and one melamine based.

Proportioning

4. The proportioning work, indicated that it is indeed possible to achieve workable, low W/C concrete with various combinations of the selected materials. Slumps in the r nge up to 8 in. were secured with water-cementitious ratios approximating 0.25 and without segregation or harshness. During the proportioning study, however, it became apparent that a slight reduction in W/C or slight increase in admixture dosage could significantly change the workability of a mixture. A decrease of 0.01 in W/C could make a mixture very sticky or an increase of 0.1 percent in admixture dosage could result in a harsh mixture. Apparently, these changes are the result of working near the critical minimum amount of water (W/C = 0.25 and the critical maximum dosage of admixture. Typical mixtures are given below (W/C = 0.25; admixture, 1.0 percent by weight of cement):

Mixture No.	Cement/Silica Fume/Fly Ash, lb/yd^3 each	Compressive Strength, psi 7 days	28 days	90 days
1	940/0/0	10,000	12,000	14,000
2	799/0/141	8,000	10,000	14,000
3	799/141/0	11,000	14,000	16,000
4	658/141/141	10,000	13,000	15,000

Results

5. As indicated above:

a. Compressive strengths of approximately 10,000 psi may be attained at 7-days age with the materials used and the slump specified.

b. Compressive strengths of 12,000 psi may be achieved at 28-days age.

c. Compressive strengths of 15,000 psi may be attained at 90-days age.

Tensile strengths of approximately 1,200 psi (10 percent of compressive strength) were achieved on several mixtures. Young's modulus of elasticity determined on representative samples averaged 6.0 by 10^6 psi, twice the normally accepted value for conventional concrete. Unit weight, shrinkage specific heat, diffusivity, thermoconductivity, and coefficient of thermal expansion have been found to fall generally within the usual range for lower strength concretes.

Application

6. Batching, mixing, transporting, placing, and control procedures for high strength concrete are not essentially different from procedures used for lower strength concretes. However, special attention is required to ensure a high strength uniform material. Special consideration should be given to minimizing the length of time between concrete batching and final placement in the forms. Delay in concrete placement can result in a subsequent loss of long-term strength or difficulties in concrete placement. The economic advantage of using high strength concrete for specialized applications has been clearly demonstrated. The ability to reduce the amount of reinforcing steel in columns without sacrificing strength and to keep the columns to an acceptable size has been an economic benefit to owners of high-rise buildings. In addition, some applications in long-span bridges also have occurred. There also have been applications where concrete of a high-compressive strength has been needed in order to satisfy special local requirements. These have included dams, prestressed concrete poles, grandstand roofs, marine foundations, and manufacturing processes.

AIRBORNE ROOF MOISTURE SURVEYS

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Design deficiencies, improper construction, and subsequent neglect all contribute to the numerous problems that have been experienced by membrane roofs over the past two decades. Moisture is the primary enemy; it commonly enters through flaws in the waterproofing membrane, with most flaws occurring at flashings and penetrations. Even if these roofs are inspected periodically, it is often impossible to locate flaws visually. Many membranes "look like a million and leak like a sieve." Periodic visual inspections of roofs are certainly appropriate, but they have limitations; thus, the need for nondestructive roof moisture surveys.

Commercailly available nuclear, capacitance, and infrared devices can detect moisture in roofs (Reference 1).

In the Army, most roof moisture surveys have been done using hand-held infrared scanners. The infrared technique examines 100 percent of the roof's surface and can find small areas of wet insulation that a nuclear or capacitance grid survey may miss. Infrared surveys are also much faster than the other two methods. For several years, a team from the Army's Facilities Engineering Support Agency (FESA) has been walking on roofs at night with infrared scanners. They have surveyed millions of square feet of roofs.

In response to the need for rapidly surveying many more Army roofs, several airborne infrared scanning techniques were evaluated some years ago.

The consensus of these early studies was that airborne roof moisture surveys were valuable for reconnaissance, but follow-up, on-the-roof surveys with hand-held infrared scanners were needed to accurately locate all wet areas.

In 1983, additional studies were conducted by CRREL to determine the value of airborne infrared surveys with scanning systems that look straight down (Reference 2). A new scanner, designed for external mounting on helicopters and fixed-wing aircraft, was evaluated. Mounting hardware was designed and built so it could be used on Army helicopters (Fig. 1).

It is gimbal-mounted and can be pointed in different directions from inside the aircraft by an electronic joy-stick control.

The new system accurately located wet areas. It has a normal lens and a narrow-field-of-view (i.e., telephoto) lens. The normal lens is used to spot the proper building some distance away. Once the helicopter is overhead, a flick of a switch allows a detailed roof moisture survey to be conducted with the narrow-field-of-view lens. A thermal image of a roof containing wet insulation is seen through this lens as shown in Figure 2.

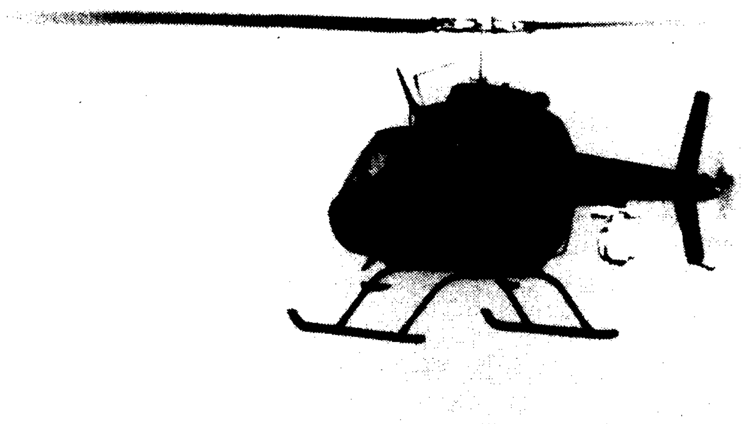

Figure 1. Infrared scanner mounted on an OH-58 helicopter.

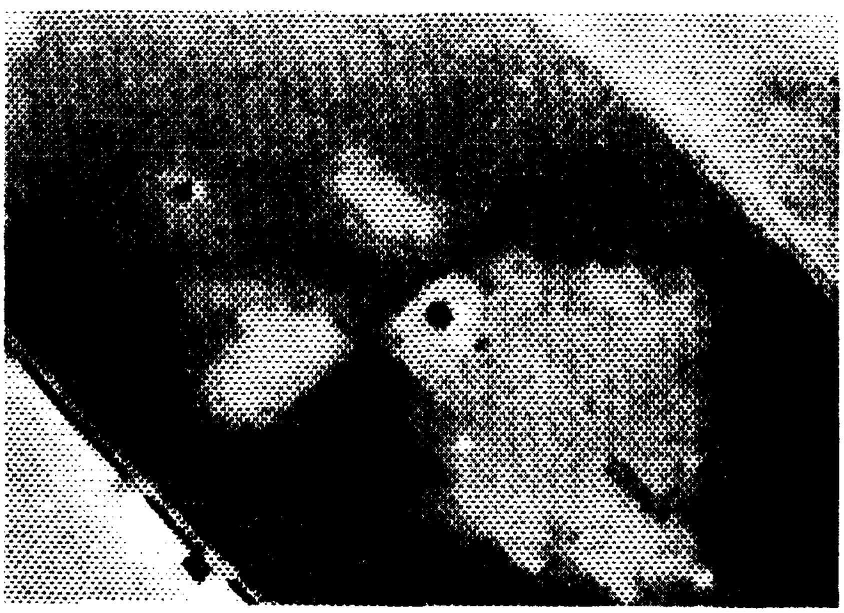

Figure 2. A typical thermogram image of a roof which shows areas underlain by wet insulation (i.e. bright areas).

This system has been demonstrated in Alaska, New Hampshire, Maryland and Florida. At Fort Wainwright, Alaska, in a couple of hours, 78 roofs were surveyed. Had these roofs been scanned on the roof, that job would have taken about a month. The roofs were then inspected visually and 247 two-inch-diameter core samples were taken of the membrane and insulation to verify infrared findings. Plans to repair and replace Fort Wainwright roofs are now based on these findings.

Many private firms can obtain core cuts for verification, conduct visual inspections, and write reports. At Fort Detrick, Maryland, we involved a private firm in the follow-up work on 16 roofs. They did a fine job.

Recently another private firm began to offer airborne roof moisture surveys using the hardware shown in Figure 1 except that they mount it on fixed wing aircraft.

Roofs cost several dollars a square foot to replace. No new or replacement roof is perfect; periodic roof moisture surveys, which cost a few pennies a square foot, are effective in detecting problems. The techniques being developed at CRREL for mapping-quality airborne infrared roof moisture surveys appear to be quite cost-effective where numerous roofs within a short distance of each other need to be surveyed. By periodically investing a small amount of money in roof moisture surveys, visual inspections, and preventive maintenance, the Army will avoid the cost of replacing many membrane roofs that fail prematurely.

Numerous research and case study reports on roof moisture surveys are available (Reference 1 contains an extensive list of references). CRREL researchers continue to work closely with engineers of the U.S. Army Facilities Engineering Support Agency (FESA) to ensure that the latest advances in infrared roof moisture detection are being used by the Army. A brochure on their "Roofing Systems Analysis" is available from FESA-EB, Fort Belvoir, VA 22060.

The Roofing Industry Educational Institute (RIEI) short course "Roof Inspection, Diagnosis, and Repair" contains information on roof moisture surveys and other aspects of roof maintenance. This course is offered several times a year at various locations across North America. For details, write RIEI, Ste. 100, 6851 S. Holly Circle, Englewood, CO 80112.

Acknowledgements: CRREL research and development activities relating to roof moisture surveys have been funded by the Office of the Chief of Engineers.

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PROTECTED MEMBRANE ROOFING SYSTEMS

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In the protected membrane (PM) roof, the membrane is protected from thermal shock, solar radiation and mechanical abuse by layers of insulation and ballast installed above (Fig. 1). A filter fabric between the ballast and the insulation "rafts" the system together, reducing the amount of ballast needed. The filter fabric also keeps dirt out of the system, facilitating drainage. In PM systems, the membrane may be a conventional bituminous built-up material or one of the more recently developed single-ply membranes of rubber, plastic or modified bitumen. One advantage of some of the single-ply membranes is that they need not be adhered to the roof. To date, the only insulation which has proved to be sufficiently moisture resistant to be used above the membrane in PM roofs is extruded polystyrene. Concrete pavers, gravel and crushed rock are used as ballast.

The patent for this proven membrane roofing system expired in 1985, thereby removing the sole-source procurement issue that has hampered its use by government. Several competitive systems are already on the market. They are expected to provide long life and low maintenance costs.

At CRREL we have conducted laboratory and field investigations of PM systems for over a decade. Recently we have documented the construction of PM roofs at Army installations in Alaska and Massachusetts. Reports and

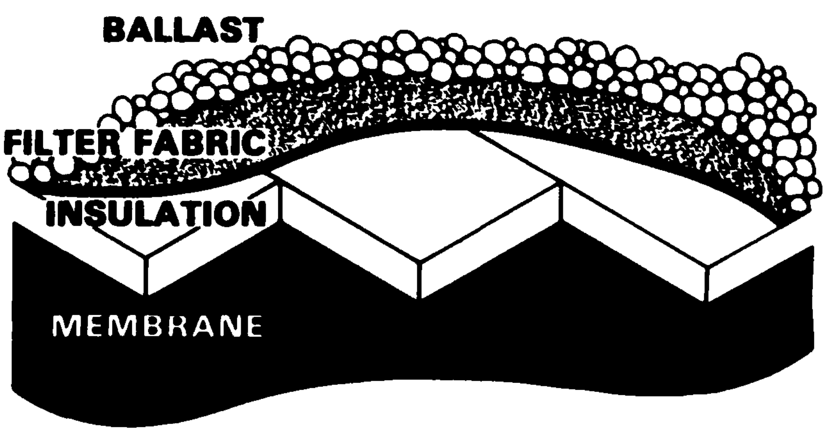

Figure 1. Isometric of a protected membrane roofing system.

videotapes are being prepared on these demonstrations and additional demonstrations are scheduled in 1986, 1987 and 1988. Design guidelines for PM systems are being written as is a Corps of Engineers Guide Specification.

CRREL research on PM roofs and our recent demonstrations of these systems have been funded by the Office of the Chief of Engineers.

Information on PM roofs is available in the following three reports that can be obtained from CRREL:

"Protected Membrane Roofs in Cold Regions" by H.W.C. Aamot and D. Schaefer 1976, CRREL Report 76-2.

"Observation and Analysis of Protected Membrane Roofing Systems" by D. Schaefer, E.T. Larsen and H.W.C. Aamot, 1977, CRREL Report 77-11.

"Roofs in Cold Regions' by W. Tobiasson, 1980, CRREL Miscellaneous Paper 1408.

Additional information can be obtained from the author.

MEASUREMENT OF CEMENT AND WATER CONTENT OF FRESH CONCRETE

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Portland cement concrete (PCC) is an unusual construction material in that it is manufactured as it is used and cannot be evaluated for acceptance prior to its use. Through the National Cooperative Highway Research Program (NCHRP), the Waterways Experiment Station (WES) evaluated seven test procedures for the rapid determination of cement, water, or both contents in fresh PCC. The procedures included the Rapid Analysis Machine, Concrete Quality Monitor, Nuclear Cement Content Gage, Centrifuge, X-ray Emission Spectrometer, microwave oven, and hot plate. Sixty-one PCC mixtures were designed and used to evaluate the seven test procedures in a side by side comparison. These mixtures contained conventional concrete material such as portland cement, tap water, natural and crushed fine and coarse aggregates, high-range water-reducing admixtures, accelerating admixtures, pozzolan, and pulverized granulated iron blast furnace slag.

Operators were trained and experienced technicians, engineers, and scientists on the various lab test procedures. All procedures involved setting up, extensive calibration, performing the test, cleaning up, and repeating four additional iterations for statistical evaluation. All the procedures had minor problems associated with each such as NRC license, precautions, unknown chemicals, lengthy time of testing, equipment cost, availability, etc. However, all the procedures were tested and evaluated to determine the procedure best suited for use as part of a quality assurance program.

The overall result of the test program was that no single test procedure proved to exhibit better measurement characteristics for determining cement, water, or both contents of all the sixty-one PCC mixtures studied. The various methods exhibited strong points as well as weak points toward the rapid analysis of fresh PCC. Some procedures were less affected by such factors as cement factors, aggregate types, aggregate ratios, prolonged mixing, admixtures, additives, and low water-cement ratios than other procedures. The PCC mixtures designed for a particular construction project really begins to dictate which procedure(s) would be best suited for determining cement or water or both contents at the 90-percent confidence level.

Acknowledgment. The Waterways Experiment Station acknowledges the sponsorship of this research by the National Cooperative Highway Research Program, Transportation Research Board, and the National Research Council.

Analysis of Aluminum Weldments to Establish the Composition of Filler Metal used in the Weld

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This program was to develop a procedure to analyze an aluminum weld of unknown origin, and be able to determine from it the filler metal alloy which had been used to produce the weld. The particular filler metal used in a weld has a tremendous influence on the physical and mechanical properties, aesthetic characteristics, and general weldability of the weldment. The capability of identifying the filler metal is very useful in weld failure analysis by determining whether an incorrect filler metal was used for the design application or if there was an area of severe non-homogeneity which could cause failure.

In forming a weld, the molten filler metal mixes with molten base metal, forming a non-homogeneous weldment. The amount of mixing depends on various welding parameters. Because of the inconsistent mixing of base and filler metals, it is difficult to identify the filler metal which had been used. In this program, a series of welds of known base metal/filler metal (b/f) combinations were used to study the effects of mixing in each b/f combination. The alloys selected for the program are given in Table I. These welds will be used as references, establishing the element composition range which will be found in a given b/f combination. The joint designs selected for examination were ¼ inch single pass fillet welds and mulitiple-pass V-groove welds in ½ inch plate.

Table I

Nominal Aluminum Alloy Compositions: [1,2]

	Mg	Si	Mn	Al
Filler Metal				
4043	0.05	4.5-6.0	0.05	93.0-94.0
5356	4.5-5.5	0.25	0.05-0.20	93.0-94.0
5556	4.7-5.5	0.25	0.50-1.0	92.0-93.5
Base Metal				
6061	1.06	0.6		97.9
5456	5.1	...	0.8	93.9
5086	4.0	...	0.4	95.4

The welds were sectioned and ground to 600 grit in preparation for testing. The cross-sections were analyzed by three(3) methods; chemical etch, energy dispersive spectroscopy coupled with scanning electron microscopy, (SEM/EDS), and x-ray fluorescence (XRF). A chemical etch solution of 0.5% hydrofluoric acid was found to differentiate between weldments containing 4043 and those with 5000 series filler metal. The weldments containing 4043 filler metal etched gray and dull, showing a definite fusion zone. The welds containing the 5000 series filler metals appeared bright, some showing a distinct fusion zone after etching. No etchant was found which would differentiate between the welds containing 5356 filler metal from those with 5556 filler metal.

The SEM/EDS system was an Amray 1200B with an EDAX 9100 spectrometer. We used this system to map the composition variations across the weldment cross-sections, in order to identify trends in the element paths. This would give some valuable information on mixing and segregation of the elements. Unfortunately, the work conducted gave no conclusive results.

The XRF system was used to do macroscopic elemental analysis of the cross-sections of the welds. The system used was a Kevex 0700 XRF unit with a 7000 microprocessor analyzer. The Kevex is a fully quantitative system with software which uses reference materials of known composition to determine "calibration constants (CC)" to use in calculations for the quantitiative analysis.[3] The CC indicates how efficiently an element line is excited by a specific target at known operating conditions. The CCs are related to the composition of the material, the concentration and peak intensity of the elements of interest, the absorption coefficients of the elements in the material, the excitation conditions used, the primary spectral distributions and fluorescent yields. A CC is calculated for each line (K,L,and M) of each element to be determined as the unknown. The accuracy of the analysis depends on the reference material being as similar to the unknown sample as possible in surface preparation, element content and concentration. CCs were established based on know filler metal alloy composition. Using these CCs, the base metals, filler metals, and then weldment cross-sections, were analyzed.

For the XRF analysis, a mask was used to isolate the area of interest within the weldment from the rest of the sample. One mil of crystalline filter paper with a 5mm mask hole diameter was used. This hole diameter was determined to be the most reliable for analysis. The cross-section was positioned on the mask so the analysis was taken as close to the weldment surface as possible. This region was found to have the least amount of mixing, and therefore was most like the filler metal in composition.

As expected, the base metal alloy greatly influences the composition of the weldment. Therefore the base metal must be determined for each unknown before the weldment may be accurately analyzed. Separate composition ranges had to be set for each b/f combination. For example, from the analysis, the manganese level found for a 5456/5356 weldment was approximately the same as that for 5086/5556, despite the fact that there is a large difference in the manganese content of the two filler metals.

Work is continuing to improve the CC values being used, in the XRF analysis as well as improvements in the overall procedure. We also will increase the number of aluminum alloys included, and evaluate use of the basic principles for steel welds.

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